# DEVELOPING MATERIALS FIRE RESPONSE INFORMATION FOR ASSESSING FIRE HAZARD AND RISK

by

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**Abstract**

In the presence of a fire, materials and products may respond by producing heat and flames, particulate smoke, and toxic and contaminant gases. This paper summarizes the contributions of products to the growth of fire hazard, offers a framework for reducing the multiple constraints on materials fire specification, characterizes the properties to be measured, and identifies research priorities to bring this concept to reality. This approach offers enhanced freedom for the development of new materials whose proliferation will contribute to an improved degree of fire safety.

Key words: fire, flammability measurements, product safety, hazard assessment

## I. INTRODUCTION

There is general agreement among fire safety professionals in the United States that fire losses and costs are too high. Further, there is general agreement among the manufacturers of building, finishing, and furnishing products that both the complexity of the required approval process and the often multiple requirements for obtaining approval are major deterrents to the introduction of new, more nearly fire-safe products. The current code system offers no reward for products that outperform the minimum fire standards, and our litigious climate discourages products whose future fire performance might be different from the established norm. What is needed is an improved regulatory system using a simplified set of product fire safety requirements whose function is to reduce these barriers to the use of less flammable products. When manufacturers can capture the benefit of producing such goods, market forces will lead to their proliferation and improved fire safety will be achieved, likely at lower cost.

A solution to this problem is properly viewed as part of a total system performance construct, into which the key properties both of the products and of the fire sensing/intervention/control components are introduced for a given occupancy. The desired or required degree of fire safety could be met by control of either moiety or, most likely, by some combination of them. The projected performance of each component needs to be based on a suite of logical and technically sound representations, the input data for each of which is obtained from (a set of) validated measurement methods.

This paper addresses one part of this: the contributions of the materials alone, with the provision that their behavior might interact with the other components. The ideas presented here are an amalgam of some offered by the author, some that arose in numerous conversations with colleagues (both within the NIST campus and without), and others that are common knowledge. While all are greatly appreciated, specific attributions of these ideas are difficult since the distinction among these sources has been blurred by time and multiple repetition. I hope this arrangement of these ideas, still in an evolutionary progress, will provoke more thought and action, leading to implementation of a practical suite of product performance measures.

## II. SIMPLIFYING CONCEPTS

There are a large number of fire scenarios. Each of these could be (and often is) interpreted to impose differing requirements on each potential combustible. There is already a long list of flammability measurement methods developed to date, and it could grow further as successive fires reveal additional nuances.

There are two concepts that could greatly reduce the testing requirements for materials regardless of the construct for flammability control. These, in turn, direct us toward a discrete set of research priorities *en route* to a small set of product performance data needed for a solid first-cut hazard analysis of product performance.

### A. Post-Flashover Fires as the Principal Problem

The first simplification is based on the evidence from the U.S. fire statistics that small (pre-flashover) fires are infrequently fatal [1] and cause only a modest fraction of the total damage to property. Thus: *a product evaluation strategy that focusses on preventing a fire from approaching the point of flashover is likely to be successful in reducing losses.* In situations where large property losses (*e.g.*, extensive loss of electrical power, contamination of critical electronics) might result from localized fires, extraordinary control of pre-flashover conditions is warranted. Under one fifth of the fire deaths result from people being intimate to a small fire [1], such as from clothing being ignited or close contact with the smoke from smoldering pillows, bedding. These are best addressed by control of the ignition process and are not addressed further here.

### B. Prevalence of a Limiting Hazard

In any fire, there are multiple possible causes of damage. Harm to people can result from smoke inhalation, obscuration of escape routes by smoke, and burns from both radiant heat and direct contact with flames. Property losses are exacerbated by high levels of heat generated from one or more burning objects, flame spread to adjacent combustibles, contamination of sensitive systems, etc. The second simplification arises from the concept that in many fire scenarios, one of these hazards reaches an undesirable degree of seriousness well before the others. Which one is the first, or limiting, hazard depend on such factors as the nature of the fuel(s), occupancy, environmental conditions, etc.

With regard to life safety, analysis of U.S. fire deaths shows that about 3/4 of the fire deaths arise from smoke inhalation, generally from fires that have progressed beyond the room of origin [1]. Further analysis shows that only extremely toxic smoke can reach fatal levels if the fire is small enough for the person to be nearby [1]. Combining these results with the thesis of the prior section, a good hypothesis is: *the limiting life safety hazard from post-flashover fires is smoke inhalation and from pre-flashover fires, the burns from the flames themselves.*

The limiting hazard for property loss is different. For most cases, the smaller the fire, the lower the losses. *The limiting hazard is the heat released from the combined combustibles* [2], *augmented by the potential for increasing the number of burning products.* Certainly a first level of containment is that the fire damage be restricted to the room of fire origin. A more desirable outcome is that the damage be confined to the vicinity of the initial ignition. Moreover, sudden flare-ups are to be avoided, since they would lead to rapid growth and spread from object to object, as well as the potential for direct burns to nearby people who might not have time to move.

There are, of course, fires and occupancy combinations in which the undesired outcome may result from even a small fire. For example, a combustible producing extremely toxic smoke could result in life loss; a small fire in a clean room might produce enough smoke to cause loss of the contained equipment and a lengthy shutdown of the facility.

## III. SIMPLIFIED OBJECTIVES

### A. Prevent Flashover

Once ignition of the initial combustible occurs, the small fire needs to be kept small. The time between the first burning object (of reasonable size) being fully involved in flames and the compartment reaching flashover can be as little as a few minutes, if there is sufficient fuel. During this interval, the radiative feedback from the hot upper layer of the compartment accelerates the burning rate. Preventing flashover thus needs to focus on limiting the available fuel and staying below a burning rate that significantly heats the compartment.

Evaluation of a product in this light requires a representation of its burning and its role in the ignition of successive combustibles. I suggest that the model needs to address, or not address, the following aspects:

- Since the discriminating phase precedes the interval when there is significant thermal interaction with the room, the model need not include most compartment-related physics, such as radiative feedback from the hot upper layer or the effects of limited ventilation.

- It does need to address item-to-item spread potential due to the contiguity of other, already burning or potentially ignitable combustibles.

- For practical reasons, such a model needs to be usable with input data that are simple and inexpensive to generate, *i.e.* the cost of obtaining information should be less than that for performing full-scale tests of the product. This may require constructing of the model around the capabilities of only one or two bench-scale test apparatus, probably combined with modification of the device(s) to produce the types of data needed by the model.

- At the same time, the representation of the rate of heat release needs to be sufficiently sophisticated to capture the buildup toward flashover, the interaction with any suppression system present, and the timing of detectable off-products.

Such models do not yet exist. They are the subject of ongoing research, and some prototypes could be accelerated to completion in *ca.* 2 years with the support of commercial and regulatory organizations.

Armed with such models, it should be possible to evaluate whether a given combination of interior finish and furnishing products, stored commodities, and other contained materials could lead to a major fire and/or flashover in the compartment. When combined with details of the occupancy and models of the fire sensing/intervention/control components, one could make choices as to how to achieve one's objectives in limiting fire size.

In concept, it seems to this author that most of the essential input data for such a model could be derived from a modified version of the Cone Calorimeter (ASTM E 1354) [3]. This is an effective device for obtaining multiple data from samples of products that are relatively small. The measurements are to be used as characteristics of the product's susceptibility to ignition, its burning behavior, and its propensity to ignite other objects. It is, of course, important that the specimen be prepared such that the product's ignition and combustion modes replicate reality. Apparatus modification would, for instance be needed to capture the changing combustion modes as a product melts and drips.

Several measurements would be extracted from each product test, *e.g.*:

- shape and magnitude of the rate of heat release and the total heat release;
- ease of ignition, to assess the susceptibility of this product to ignition by nearby flames;
- radiant intensity of the flames, to help evaluate the likelihood of ignition of nearby combustibles;
- notation of spitting and sputtering during combustion, indicative of an alternative mechanism for igniting nearby combustibles;
- generation rate of visible smoke or other detectable species; and
- notation of any sudden increase in the burning rate, especially if it occurs early in the combustion, as a herald of burns and/or clothing ignition.

The Cone Calorimeter could be adapted to provide information on the effect of an incident suppressant on the burning rate of the specimen. However, it cannot be modified to replicate the outcome of suppression-system-driven transverse air flows on the above properties or the effect of complex commodity shape on the effectiveness of the suppressant. Thus, in formulating the options for active fire suppression, some of these performance measures will need to be included.

Inserting the output of the burning object model into a construct such as FASTLite [4] would enable estimation of whether the point of flashover is reached in the absence of any intervention. FASTLite can also calculate the times of smoke detection and thermal initiation of a suppression system, providing further boundaries for successful product fire performance.

## B. Limit Smoke Toxic Potency

As noted earlier, while the flames are small, the major threat to people is from contact with the fire plume. The smoke needs to be extremely toxic to be the limiting hazard. At present, the apparatus used in NFPA 269 [5] can be used as a screening tool. For example, one could test a sample size that produces a smoke concentration of about 0.1 $g \cdot m^{-3}$. At this level, extremely few, if any, common products should produce any animal deaths during a 30-minute exposure period plus a 14-day post-exposure period. The molecules in nearly all of these products are composed of a limited set of chemical elements. Thus, a pre-screen could be applied. Experience to date suggests that products composed only of carbon, hydrogen, oxygen, nitrogen, chlorine, or bromine would not be cause for alarm in this context. With further testing, other elements could be added to the list.

For fires that have become ventilation limited, carbon monoxide (CO) assumes a dominant role in the lethality of the smoke. Thus, the apparatus used in NFPA 269 can be used in either of two different modes.

First, use of the 6-gas (carbon monoxide, carbon dioxide, reduced oxygen, hydrogen cyanide, hydrogen chloride, and hydrogen bromide) equation and animal check tests enables determination of the importance of additional toxicants. Should any significant discrepancies from the predicted lethality be found, one would then proceed to identify the additional effecting species.

The second approach screens products for extreme toxic potency, similar to that just discussed. The thermal and oxygen-deprived conditions in such fires lead to extremely high yields of 0.2 g or more of CO per g of fuel consumed, regardless of the fuel in the tests to date [5]. The toxicity of CO is enhanced by the presence of carbon dioxide ($CO_2$), a prevalent product of the combustion of organic materials. This translates to an $LC_{50}$ of 25 $g \cdot m^{-3}$ for post-flashover smoke whose only toxic components are CO and $CO_2$ [6]. [The $LC_{50}$ is the concentration of smoke needed to kill half the test animals in a fixed exposure time. A lower number indicates more toxic smoke.] Analysis of validation tests for the apparatus showed that the results can be used to predict real-scale toxic potency to about a factor of 3 [7]. Therefore, $LC_{50}$ values over 8 $g \cdot m^{-3}$ are not distinguishable from each other. To a first approximation, $LC_{50}$ values add inversely. Therefore, if there were only a single combustible in the compartment (rare, since all potential fuels are generally burning after flashover), to make the toxic potency of the smoke significantly worse, the $LC_{50}$ value for its smoke would need to be below 1 $g \cdot m^{-3}$. Thus, analogous to the pre-flashover screen, one could test using a sample size that produces a smoke concentration of about 1 $g \cdot m^{-3}$. [This is more rigorous than the pre-flashover screen, so if the product "passes" this, there would be no need to perform that one.] Again, few products have shown more severe toxic potencies than this, and a pre-screen based on elemental composition is a strong possibility.

### C. Limit Non-Thermal Property Damage

This category includes such impacts as contamination (*e.g.*, in clean rooms) and corrosion (*e.g.*, of unprotected electronics). While research is underway to develop the means to evaluate products for these effects of their fire performance [8], the dedicated resources have been distinctly less than those that had been committed to developing an approach for resolving the impacts of smoke toxicity. As a result, it is not yet possible to perform an equivalent evaluation of potential non-thermal damages from products for the following reasons:

- The criteria for damage are more diverse and much less defined here than for smoke toxicity.
- While test methods for corrosion of exposed electronic circuits are being considered, there remain concerns about the validity and universality of the choice of targets.
- Since the extent of corrosion is dependent on the "soaking" interval, the losses would depend on the timing of and potential for cleanup.
- The bench-scale methods have not yet been validated with real-scale tests.
- There are still significant gaps in understanding which combustion-generated species are responsible for the damage, and therefore studies have not been performed to determine their transport efficiency from the fire to the sensitive sites.

Thus, from the viewpoint of this class of hazard, there is significant work to be done to define how small a fire is small enough or what other materials properties need to be controlled.

## IV. PRODUCT HAZARD ANALYSIS

Given the wide range of fire scenarios and that the location and composition of nearby combustibles may not be readily controlled, a line of thinking is needed for using the above information in evaluating products. Figure 1 is a simplified example for a product in the presence of other combustibles. The only hazards included are death and generic outcomes of a post-flashover fire; non-thermal property damage is not included; products that are too small to contribute to fire hazard or that are already fully protected need not be included. Of course, to make such a diagram practical, clear metrics for each of the decision points are needed. Note that in this example, there are possibilities in which the product performance is sufficient by itself, where the interaction with detection and intervention is important to consider, and even where there is no information regarding the acceptability of the product.

## V. SUMMARY AND RECOMMENDATIONS

This analysis suggests that it is possible to arrive at predictions of the broad contributions of burning products to thermal and personal fire hazards. Two complementary priority efforts are needed to bring this capability to reality:

- Development of prototype models for the burning of the most important combustibles.
- Adaptation of the apparatus and procedures in ASTM E 1354 and NFPA 269 to obtain the needed data for these product models.

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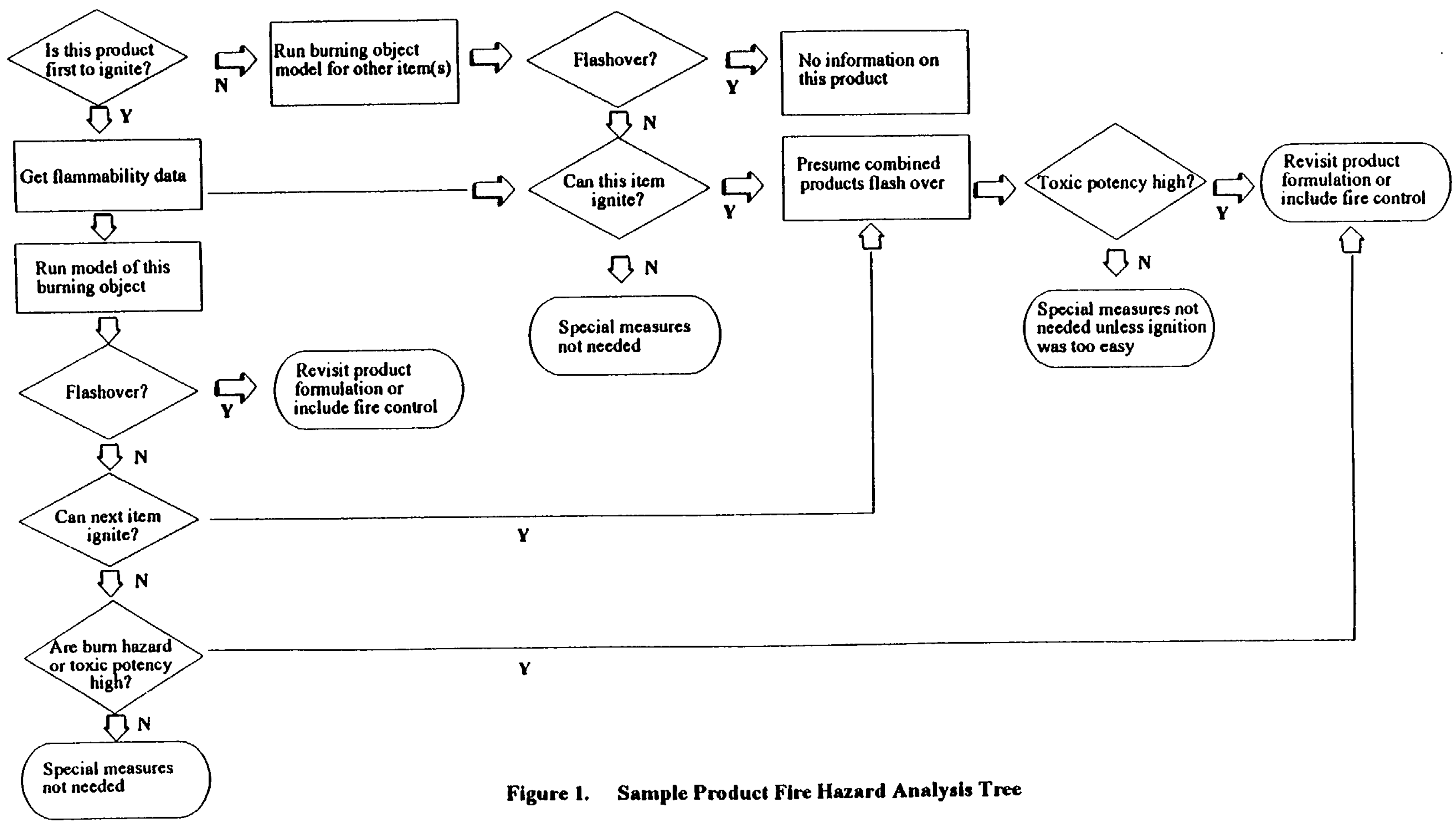


Figure 1. Sample Product Fire Hazard Analysis Tree

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